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INTEGRATED MANEUVERING LIFE SUPPORT SYSTEM

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13. ABSTRACT

Successful completion of a design study of an extravehicular space suit assembly with an integrated life support system has led to the fabrication and evaluation of a human factors mockup. This mockup consists of a two-piece hard torso with soft arms and legs. A full bubble helmet and pressure gloves complete the pressure suit system. The hard torso is a volumetric representation of an integral life support system. It also contains an operational cold-gas propulsion system and controls and display panel. Sixteen thrusters provide accelerations of 0.3 ft/sec.^{2} in three degrees of translation and 10 to 20 degrees of rotation.

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SUMMARY

The work accomplished during the course of this program represents a logical extension of that conducted under the program, "Engineering Design Study of a Space Suit With an Integrated Environmental Control System". That work was reported in AMRL-TR-68-122 dated October 1968. This program consisted of three major efforts:

- The addition of a cold-gas maneuvering system to the existing integrated EVA space suit/life support system design.
- Fabrication of a Human Factors Mockup which is a mass and volume representation of the modified design.
- Evaluation of the Human Factors Concept Mockup.

The addition of a cold-gas maneuvering system to the existing suit life-support system design produced an advanced personnel protection system capable of totally independent extravehicular operation. The system provides environmental protection, life support, and maneuvering which, combined with unaided expendables recharge, results in the capability of extravehicular mission durations limited only by the crewman's endurance rather than hardware design.

The Human Factors Mockup is a two-piece hard torso with soft arms and legs. The torso pieces when joined are a volumetric and mass distribution representation of the space-qualified design. Additionally, the lower torso contains the functional cold-gas propulsion system, controls, and displays. A bubble helmet and pressure gloves complete the pressure suit assembly, which operates from vent pressure to 5.0 psig. Pressurization, ventilation, and propulsion gases are provided from external sources via umbilicals as are electrical power for the propulsion system and water for the liquid cooling garment.

Evaluation of the mockup was performed at Hamilton Standard, Windsor Locks, Conn., and on the air-bearing platform located at the NASA Manned Spacecraft Center, Houston, Texas. Testing conducted in Houston was under the cognizance of Mr. S. Martin of Crew Systems Division. Performance areas evaluated were

- Don/Doff
- Fit/Mobility
- Propulsion (Translation and Rotation)

The results of the evaluations at both sites indicated that the modular approach to integrated life support and propulsion systems is superior to the add-on technique, such as the Apollo. Don/doff time and total stowage is less than that for equivalent but separate functional units. The grouping and location of controls and displays is superior to a more posterior position. Finally, overall results indicate that the integrated life support/suit/maneuvering system concept is valid and that specific design approaches to satisfy mission requirements should be generated.

FOREWORD

This study was conducted by Hamilton Standard, Division of United Aircraft Corporation, Windsor Locks, Connecticut, 06096. The effort was performed under Air Force Contract No. F33615-67-C-1946, Amendment P004, project No. 7164, "Aerospace Protective Technology," task No. 716411, "Aerospace Pressure Outfits." The study summarized in this report was conducted during the period 1 July, 1968 through 1 October, 1969. The study was partially funded by the Air Force Aero Propulsion Laboratory Directors Funds and the National Aeronautics and Space Administrations Manned Spacecraft Center.

The principal investigator was Douglas C. Howard who was assisted by Philip Heimlich and Harry Cooke, Advanced Engineering Group. The contract monitors for the Aerospace Medical Research Laboratory were Mrs. Lee C. Rock and Mr. Richard E. Bennett.

This technical report has been reviewed and approved.

CLINTON L. HOLT, Colonel, USAF, MC
Commander
Aerospace Medical Research Laboratory

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SECTION I

INTRODUCTION

Continued increases in EVA systems reliability and sophistication have resulted in lengthened EVA mission duration and a wider scope of activities for the crewman. These activities have been projected to include in-space disassembly and unloading of shuttle vehicles, construction of a space station-type structure, and experimentation, maintenance, and repair tasks. An advanced personnel protection system required to accomplish such missions will provide three principal functions - life support, mobility, and propulsion.

Hamilton Standard completed a study in July, 1968 that resulted in a design of an advanced Integrated EVA suit system (IEVA) that met the first two requirements. At the conclusion of this study, the next logical development of this system was to build an operable mockup. Additionally, a cold-gas propulsion system was incorporated. The life support in the fabricated model is nonfunctional; however, it is an accurate representation of the volume and mass distribution. The system is known as the Integrated Maneuvering Life Support System (IMLSS).

OBJECTIVES

The objectives of this program were:

a. To incorporate a cold-gas propulsion system into the existing integrated EVA suit design.

b. To fabricate a human factors mock-up with nonfunctional life support system but operable cold-gas propulsion system.

DEFINITIONS

This program consisted of two distinct phases. Each phase was conducted in parallel with the other to conserve time and effort. Phase I is concerned with the design of a space qualified system version of the IMLSS. Henceforth throughout this report, IMLSS will refer to phase I or the space version of the system. Phase II deals with the design modifications and fabrication of the human factors mock-up version. Therefore, the word Mock-up will always refer to phase II or the fabricated version.

SECTION II

METHODS

A review was conducted of the system evaluation criteria and their priorities that had been established during the previous suit study. Table I lists these criteria and the priority assigned. They apply equally to the human factors mock-up and the all-up IMLSS system design with the exception of Recharge. Since the expendables package and propellant tank module are in mock-up form only, there is no recharge capability in the mock-up.

SPACE QUALIFIED DESIGN

The mission requirement for the space qualified version of the IMLSS is as follows:

- Low earth orbit
- 4-hour EVA
- 1500 Btu/hr average metabolic rate
- 4000 Btu/hr peak (4-10 minute periods)
- EV recharge
- 15-minute emergency return
- 500 lb-sec of propulsion

These requirements resulted in the addition of a cold-gas propulsion system to existing Integrated EVA suit designs. The system consists of a two-piece hard-torso assembly. The upper torso has soft arms attached to it and detachable gloves and helmet. The lower torso contains the life support system (LSS), Integrated Maneuvering System (IMS), and has soft pressure pants attached. The LSS and IMS meet all requirements listed above. Crewman thermal control is provided by a liquid cooling Garment (LCG) and a ventilation gas stream. Heat pickup by the liquid and gas systems is 80/20, respectively, at peak metabolic loads and 70/30 at average metabolic rates. Carbon dioxide control is provided by a canister containing LiOH. Humidity is controlled by condensing excess water from the gas stream. The condensed water is removed by hydrophilic wicking and transferred to a storage volume.

TABLE I
IMLSS EVALUATION CRITERIA

Priority	Criteria	Definition
1.	Safety/Reliability	The probability of no mal-function and safe operation by the crewman.
2.	Mobility	The ability of the crewman to move his limbs, torso, and neck.
3.	Volume	The pressurized all-up system.
4.	Weight	Earth-weight.
5.	Comfort	The sum total of subjective human response to wearing and operating the system.
6.	Wear	The ability of the system to withstand abrasion.
7.	Don/Doff	Time and effort plus any ex-ternal aids required to put on and take off the suit.
8.	Stowage	Effort plus volume required for stowing suit.
9.	Recharge	Time and effort required to replace all expendables.
10.	Start - Stop	Time and effort required to checkout, start up and shut/down the system.
11.	Maintainability	Time and effort required to perform routine maintenance functions.
12.	Self-monitoring	The amount of information the system delivers to the crewman about itself.

All expendables for the LSS and IMS have been placed in the front for easy access during recharge. To achieve maximum packaging density, all nonexpendables were placed in the back. All controls and displays are frontally mounted for 100% visibility and accessibility. The system configuration is shown in Figure 1. Figure 2 depicts the LSS schematic and Figure 3 the propulsion system.

HUMAN FACTORS MOCK-UP

The Human Factors Mock-up (HFM) has the same configuration shown in Figure 1. The difference is that the lower torso has no life support system. Instead, it contains the hardware and electronics necessary to operate the cold-gas propulsion system. It also contains provisions for operating with a liquid cooling garment and an external gas ventilation stream for suit pressurization and crewman comfort. The control panel indicates all necessary functions including life support; however, only the suit pressure gage, power, and liquid cooling connectors are functional. Additionally, the life support and propulsion system expendables packages are removable to simulate actual operation. The suit soft goods are root-restrained preformed convolutes with a cable restraint system.

As was required by the statement of work, off-the-shelf hardware was used in the mock-up fabrication wherever possible. There were two reasons for this: (1) the purpose of the mock-up was to evaluate the concept, not the hardware, and (2) cost limitations. Once proof of concept feasibility has been obtained, the incorporation of latest state-of-the-art hardware and design refinement will be the objective of a detailed design effort.

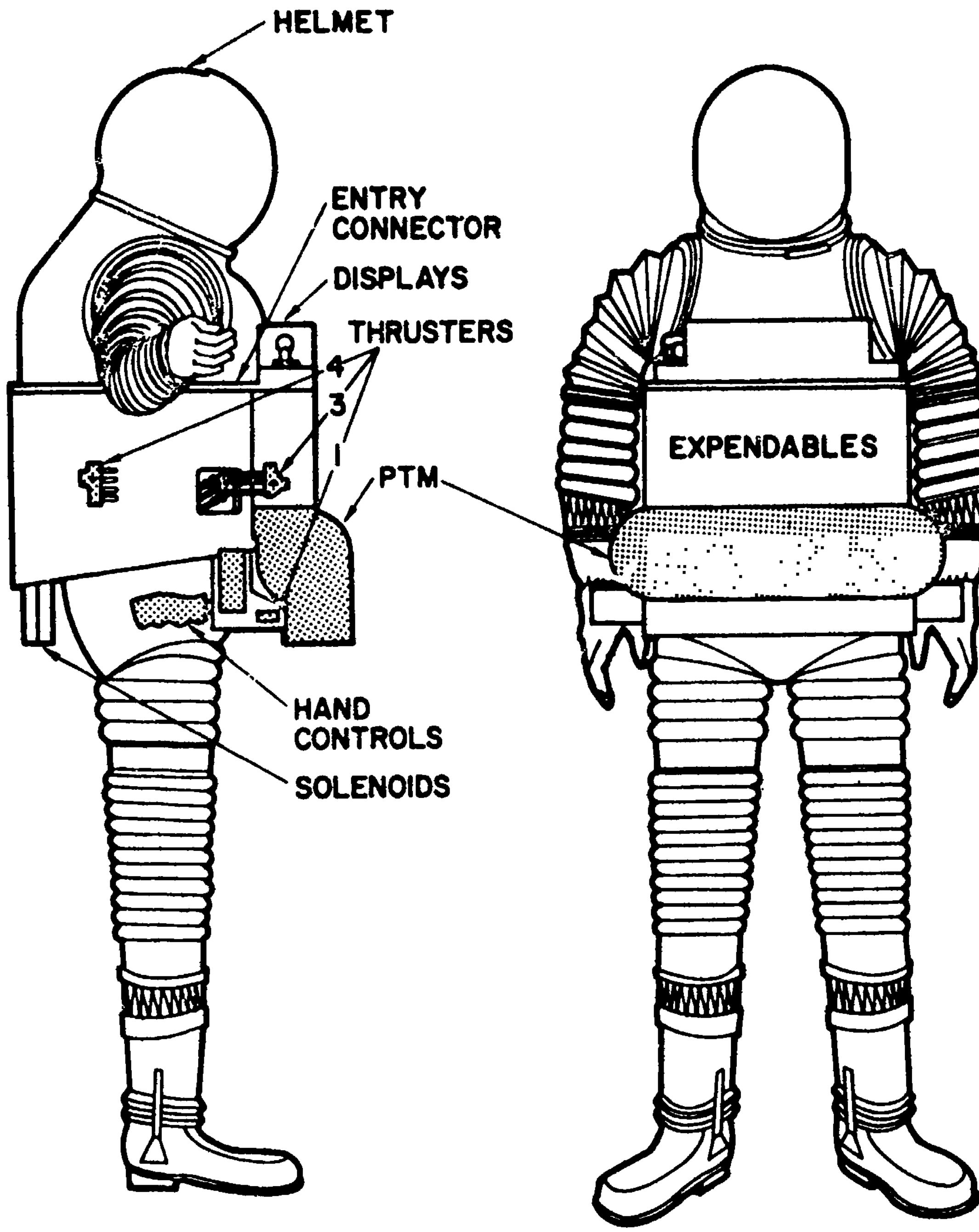


FIGURE 1. STAND-UP CONFIGURATION

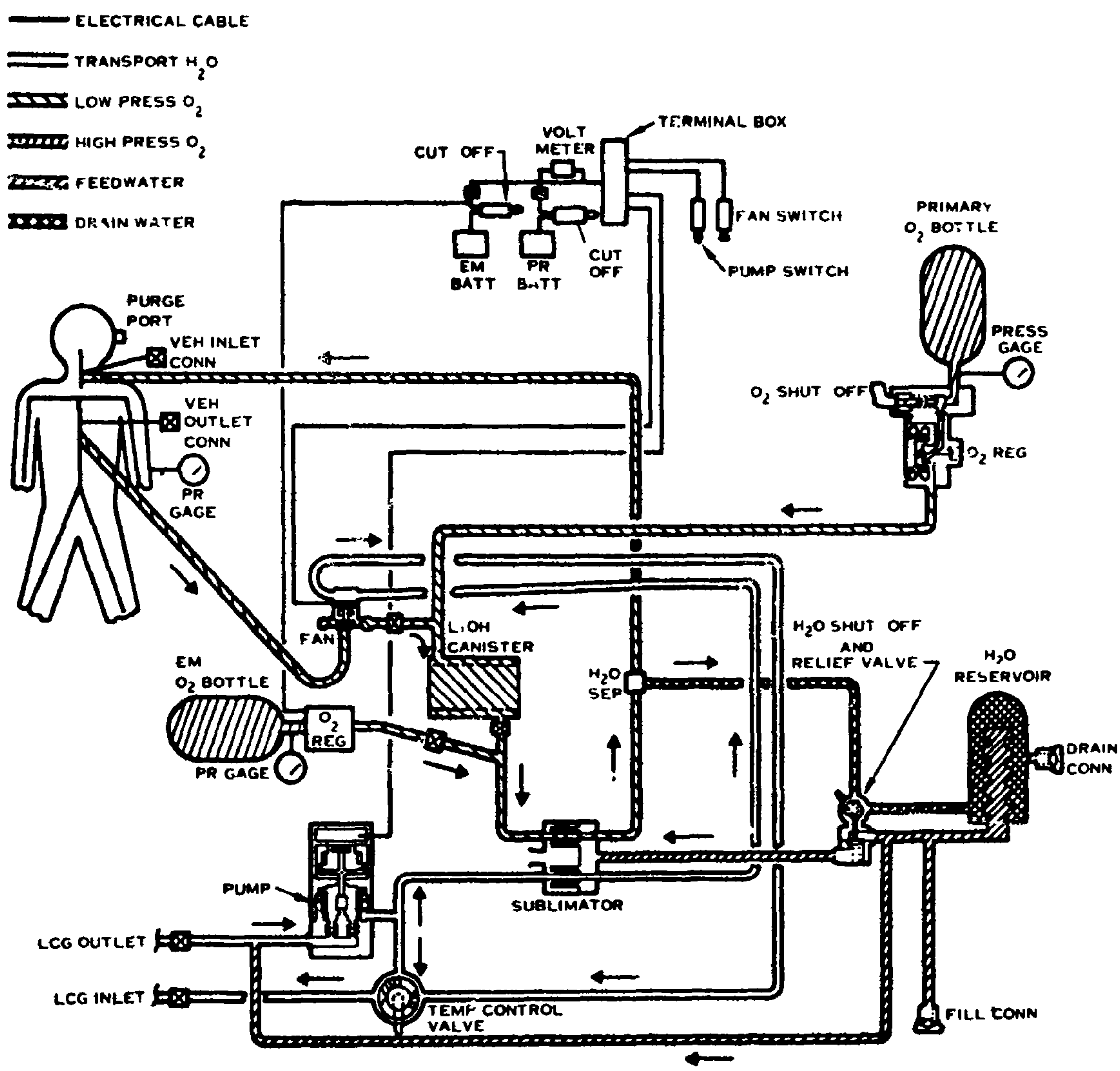


FIGURE 2. LIFE SUPPORT SYSTEM FUNCTIONAL SCHEMATIC

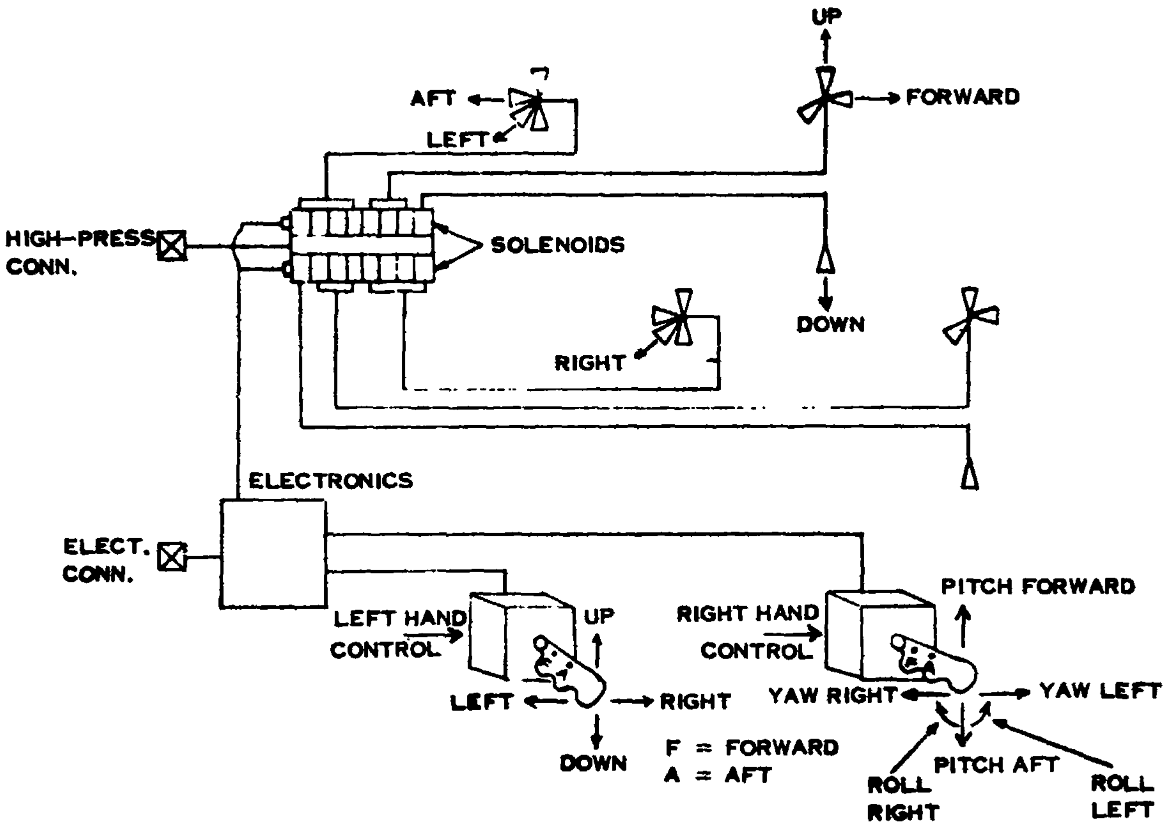


FIGURE 3. PROPULSION SYSTEM SCHEMATIC

SECTION III

CONFIGURATION STUDIES

This section describes the configuration studies conducted during the course of the program. These studies were performed in two different phases: (1) the space qualified design and (2) the human factors mock-up.

SPACE QUALIFIED DESIGN

All studies for the space qualified IMLSS used the design formulated during the IEVA program as a base. This design is described in AMRL-TR-68-122, October, 1968. The problem was to add an Integrated Maneuvering System (IMS) to this existing design with minimum impact.

Configuration study ground rules considered space qualified design are shown in Table II below.

TABLE II
CONFIGURATION STUDY GROUND RULES
SPACE QUALIFIED DESIGN

1. Six degrees of freedom - three in rotation and three in translation.
2. Gaseous oxygen propellant.
3. A total thrust of 500 lb-seconds.
4. No rate sensing or automatic thruster firing systems.
5. Removable Hand Control Assemblies (HCA).
6. Removable Propellant Tank Module (PTM).
7. Minimum envelope increase from IEVA system.
8. Maximum weight increase of 60 lb from IEVA weight.
9. Existing, easily available materials, parts, and processes shall be used.
10. The PTM shall be removable during EVA.

The system consists of a Propellant Tank Module (PTM) a Thrust Control Assembly (TCA), and two Hand Control Assemblies (HCA's). These subsystems are now described.

PROPELLANT TANK MODULE (PTM)

The PTM consists of a high pressure oxygen tank, shutoff valve, regulator, heater and battery as shown in Figure 4. It is mounted below the IEVA expendables package where the emergency return system would be. The oxygen tank is a 7500 psig cylinder. Any less pressure would result in untenable volume increases while greater pressures become impractical due to the compressibility factor. The tank will contain the one pound of emergency oxygen required for a 15-minute return plus 9.0 lb of oxygen required to produce the required thrust of 500 lb-sec. The weight of propellant is calculated as follows:

$$W_P = F/I_S \qquad F = 500 \text{ lb-sec}$$

$$I_S = 60 \text{ sec @ } 20^\circ C$$

$$= 8.34 \text{ lb}$$

Ullage and compressibility factor losses add an additionial 0.66 lb. The regulator and shutoff valve are the same as those used in the IEVA emergency return package. The regulator also has a small heater that is powered by a 160-watt-hour battery. This equipment automatically keeps the oxygen gas at 20°C during EVA propulsion or emergency return. If the heater were not present, the temperature of the gas would fall to liquification temperatures due to isentropic expansion. This would result in a reduction of specific impulse to near zero or the introduction of this frigid gas into the suit loop during emergency return. A pressure sensor sounds a tone in the crewman's earphones when the propulsion oxygen is at or near exhaustion and warns that continued thruster activity will deplete the emergency oxygen.

THRUST CONTROL ASSEMBLY (TCA)

The TCA consists of a high pressure manifold, 16 solenoid valves, 16 thrusters, and connecting lines. The manifold accepts the high pressure gas from the PTM and distributes it to the solenoid valves. Various combinations of valves open, depending on the thruster motion desired, allowing the gas to flow to the appropriate thruster nozzle. This is shown schematically in Figure 3. The solenoids are packaged in a small container at the rear of the lower torso, as shown in Figure 1. A logic circuit is also included to preclude firing of more than one set of thrusters at a time. This will prevent confusion and disorientation due to inadvertent thruster operation. The thrusters produce 1.5 pounds of thrust each and are always fired in pairs or fours to produce the required acceleration. Figure 5 illustrates the firing sequence and consequent acceleration produced.

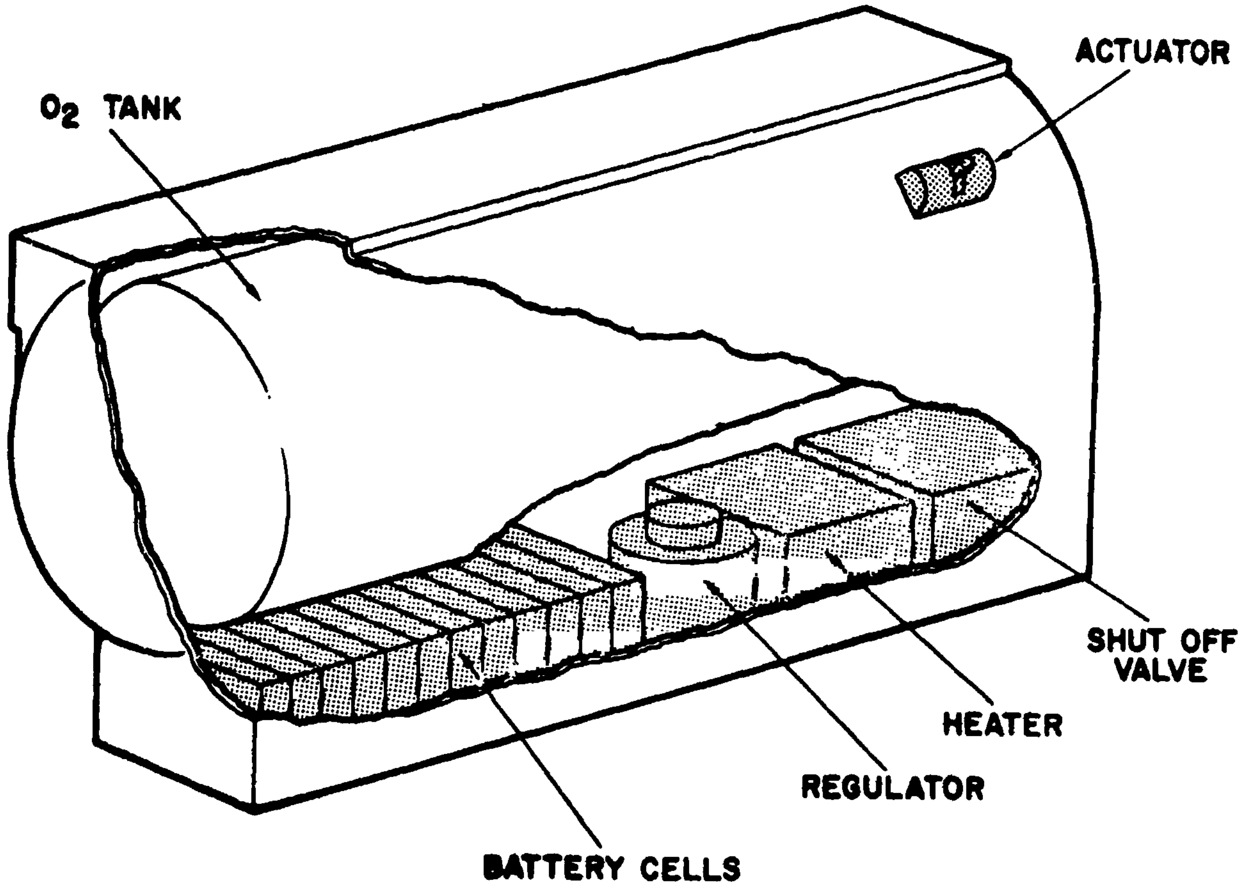
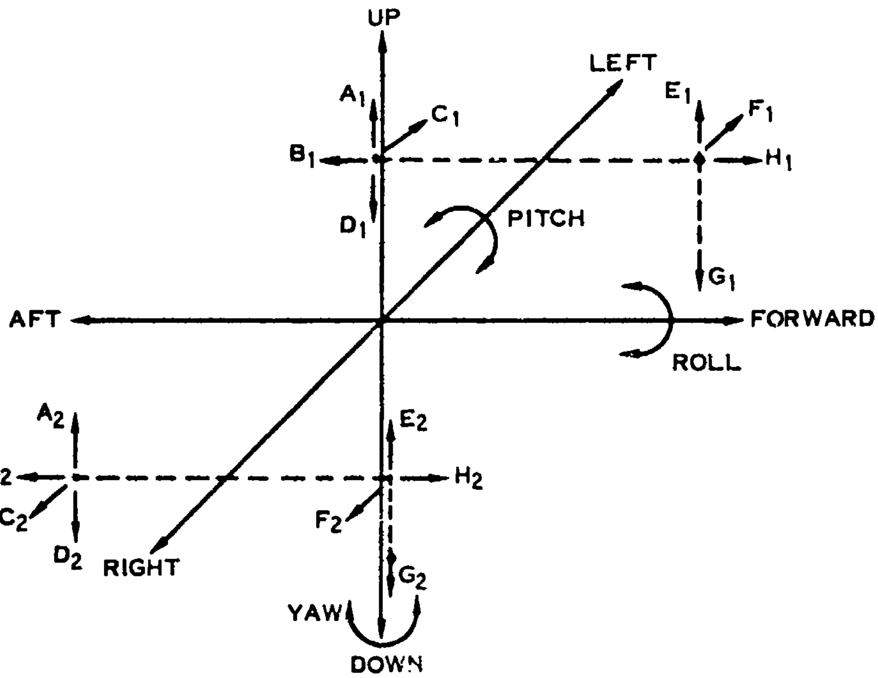


FIGURE 4. PROPELLANT TANK MODULE



TRANSLATION			ROTATION		
DIRECTION	FIRING THRUSTERS	ACC. FT/SEC^2	DIRECTION	FIRING THRUSTERS	ACC. DEG/SEC^2
FORWARD	B_1 B_2	0.3	PITCH FORWARD	E_1 E_2 D_1 D_2	10.3
AFT	H_1 H_2	0.3	PITCH AFT	A_1 A_2 G_1 G_2	10.3
UP	D_1 G_2	0.3	ROLL LEFT	A_1 E_1 D_2 G_2	15.8
DOWN	A_2 E_1	0.3	ROLL RIGHT	A_2 E_2 D_1 G_1	15.8
LEFT	C_2 F_2	0.3	YAW LEFT	C_1 F_2	20.5
RIGHT	C_1 F_1	0.3	YAW RIGHT	C_2 F_1	20.5

FIGURE 5. THRUST CONTROL ASSEMBLY FIRING MODES

HAND CONTROL ASSEMBLY (HCA)

There are two HCA's. They are mounted in the arms-down position as shown in Figure 1. This proved to be the optimum where system complexity, cost, and reliability were considered in addition to crewman operability. The HCA on the left is for translations while the one on the right produces rotations, as shown in Figure 3. Fore and aft translation have been added to the right HCA so that total freedom of flight may be had while carrying a load with the left hand.

HUMAN FACTORS MOCK-UP (HFM)

This section will describe the configuration of the HFM version of the IMLSS. Ground rules for this effort are shown in Table III below.

TABLE III
CONFIGURATION STUDY GROUND RULES
HUMAN FACTORS MOCK-UP

- Correct external configuration
- Six degrees of freedom
- Removable HCA's
- Minimum envelope increase from IEVA
- No functional life support system
- Operational propulsion system

All changes from the IEVA to the HFM were accomplished in the lower torso. Since the requirement for a life support system was deleted, a water reservoir was not required. Therefore, a simple inexpensive method of performing two reservoir functions was required. These functions are: (1) carrying the plug load and (2) providing mounting base for lower torso components. This was accomplished by substituting solid mahogany for the water reservoir. The lower half of the entry ring assembly and the pants connector plate were then bonded to the top and bottom, respectively. A back plate houses the solenoid valves and provides additional plug load carrying capability. The back plate also allows provisions for (150 psig) gas to the solenoid valves, a liquid cooling garment multiple water connector, and ventilation gas stream inlet and outlet connectors.

Mounted on the pants connector plate at the rear of the lower torso is the electrical system. It contains a 115 vac 60-cycle electrical connector for admitting power to the system. The power on/off switch and an indicating light are mounted on the control panel for ease of operation by the suited crewman. The lower torso with all functions noted is shown schematically in Figure 6. Figure 7 is a cutaway view showing the installation of the solenoid valves, manifolds, and thruster tube routing.

All hardware used in the lower torso, with few exceptions, was obtained from standard commercial sources. Program cost and schedule limitations dictated this approach. Additionally, since the purpose of the mock-up was to verify concept feasibility and not specific hardware implementation, the commercial hardware approach was judged satisfactory. Exceptions, as noted above, included the ventilation gas connectors, the liquid cooling garment connector, and the external torso water connector.

All other components of the IMLSS mock-up except the upper torso shell and chest connector were fabricated in accordance with Manned Orbiting Laboratory (MOL) Pressure Suit Assembly (PSA) drawings. This included the soft arms and legs, boots, helmet, and neck ring assembly. This MOL PSA was an existing design; hence it did not represent latest state-of-the-art improvements.

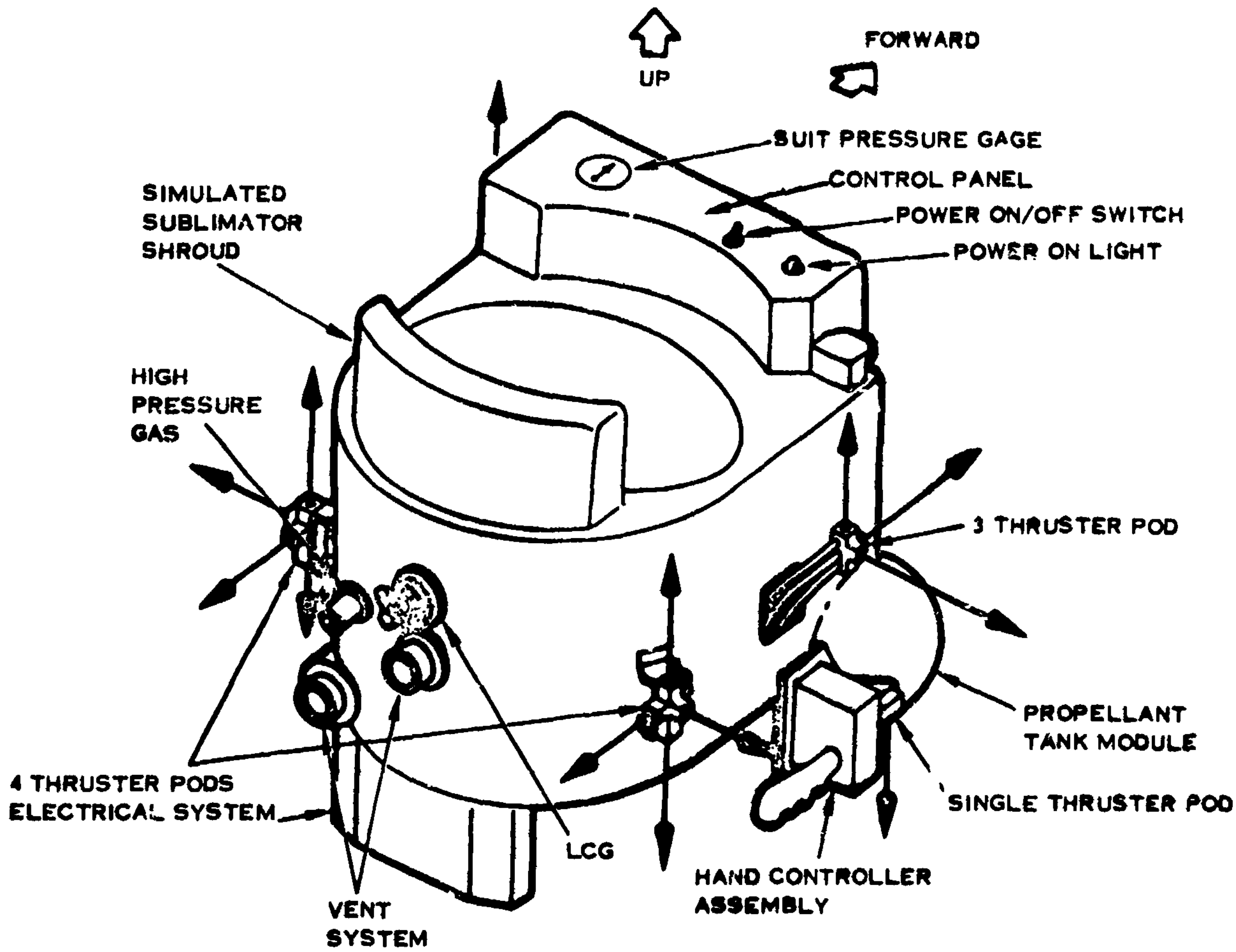


FIGURE 6. HUMAN FACTORS MOCK-UP LOWER TORSO WITH MANEUVERING UNIT

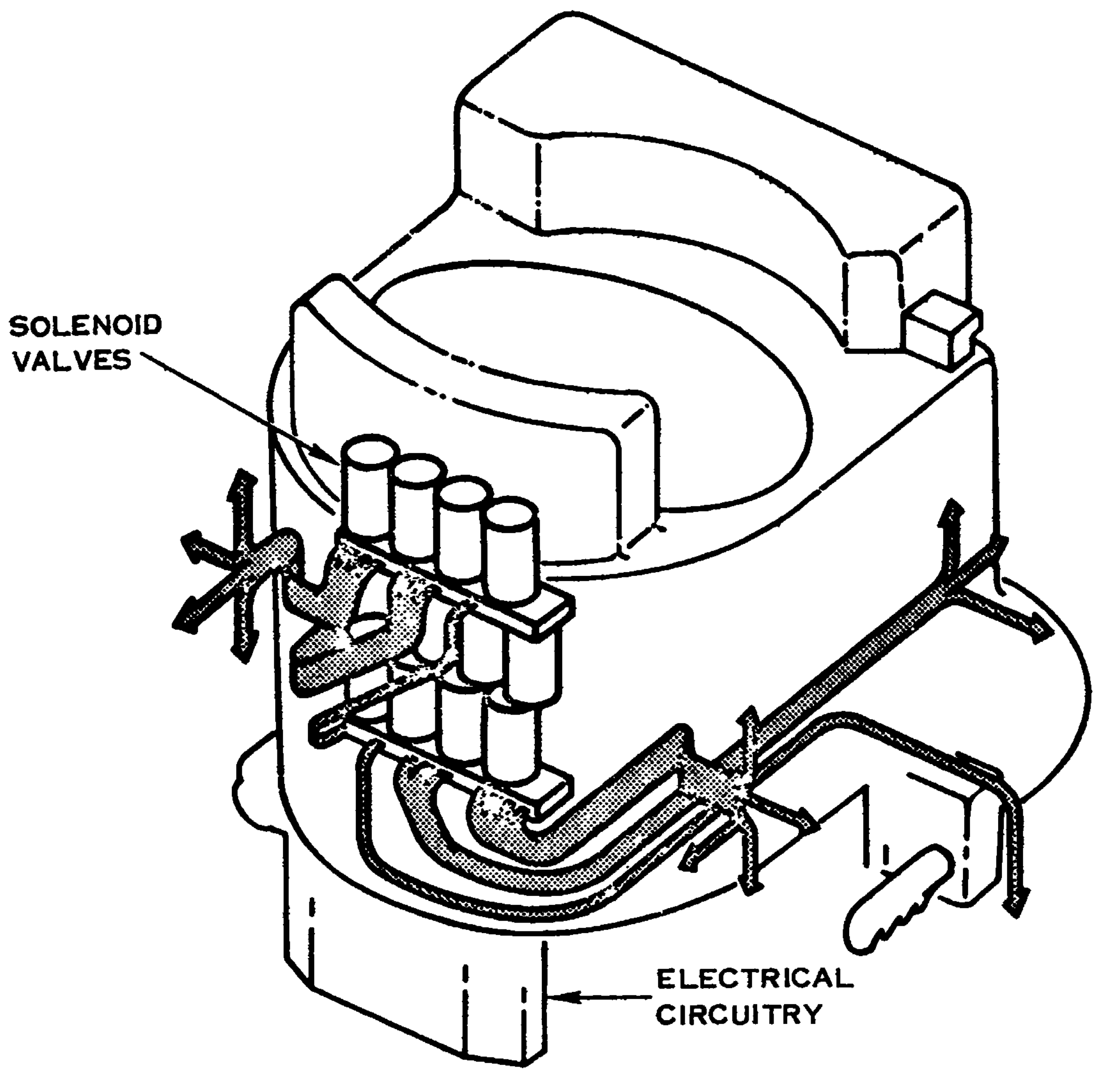


FIGURE 7. HUMAN FACTORS MOCK-UP THRUST CONTROL ASSEMBLY

SECTION IV

MOCK-UP EVALUATION PLAN FOR THE INTEGRATED MANEUVERING LIFE SUPPORT SYSTEM

INTRODUCTION

This Mock-up Evaluation Plan (MEP) describes the equipment and procedures to be used during the testing of the Integrated Maneuvering Life Support System (IMLSS) space suit assembly. The purpose of the test is to evaluate the capability of the IMLSS to perform simulated orbital EVA maintenance and repair tasks. The plan contains the following sections:

- System Description
- Stowage and Retrieval
- Don/Doff
- Fit and Mobility
- Checkout-Startup and Shutdown
- Operation

SYSTEM DESCRIPTION

The IMLSS space suit assembly human factors mock-up consists of the following major subassemblies:

- Left Hand Control Assembly
- Right Hand Control Assembly
- Upper Torso and Arm Assembly
- Lower Torso and Leg Assembly
- Expendables Package
- Propellant Tank Module

The system configuration, with these subassemblies identified, is shown in Figure 8. Succeeding paragraphs of this section of the MEP will describe each subassembly in detail.

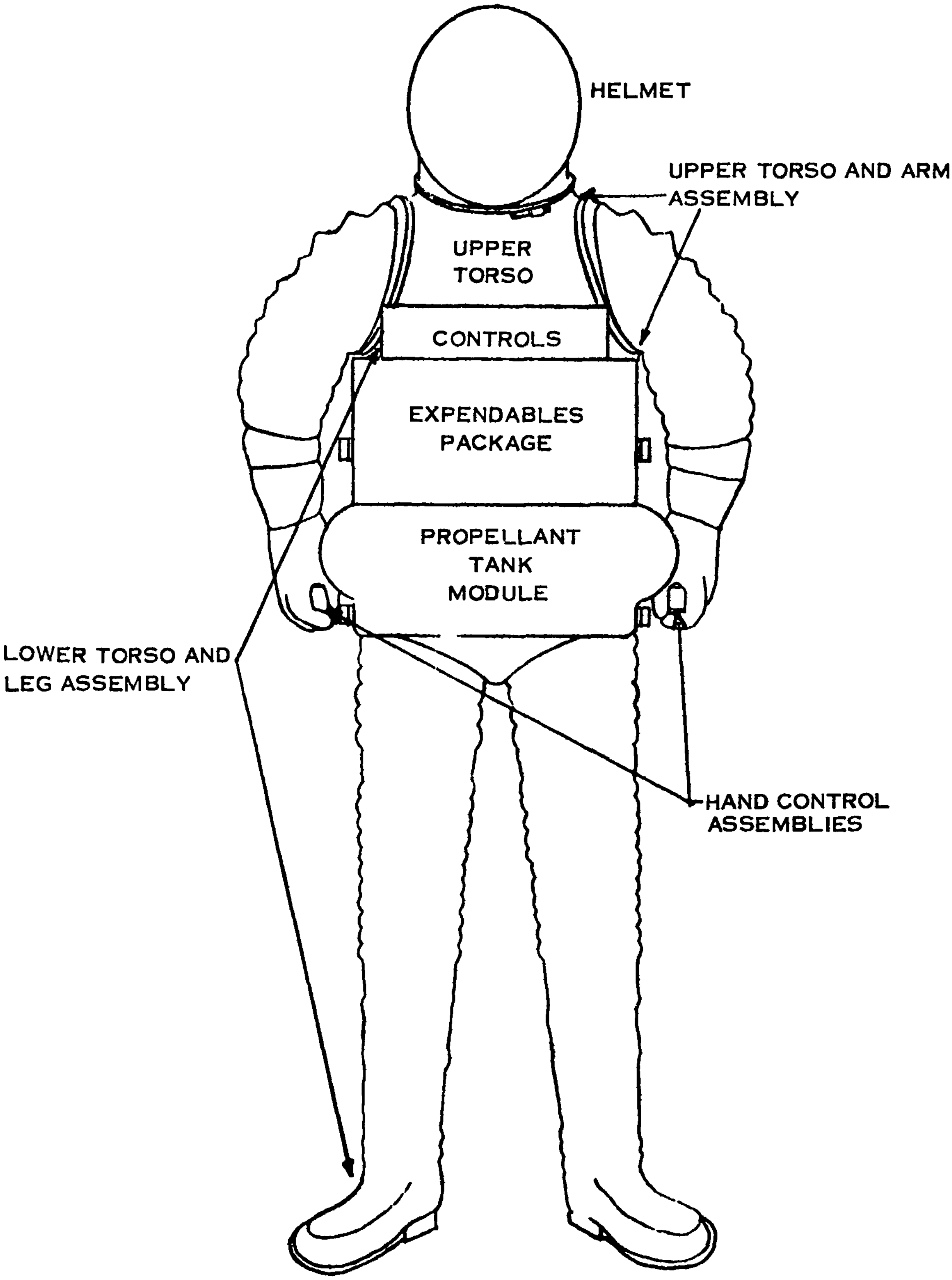


FIGURE 8. IMLSS SYSTEM

Helmet

The helmet is a full bubble containing a pressure retaining transparent visor and the male half of the neck ring assembly. An integral vent system directs the gas stream over the inside of the visor for defogging and CO_2 purging.

Upper Torso

The upper torso, shown without the soft arms in Figure 9, covers that portion of the crewman from the mid-chest to the neck and from scye to scye. It is a laminated fiberglass structure which comprises the pressure shell. It connects to the helmet and the lower torso. The female half of the neck and an 18-inch diameter male half of a neck-ring type connector, respectively, perform these functions. The upper torso also contains an integral vent system that directs the flow to the helmet and from the arms to the exhaust gas connector.

Lower Torso

The lower torso, shown in Figure 10, extends from the mid-chest to the waist. It contains the female half of the 18-inch diameter connector, which mates with the upper torso. Additionally, the soft pants are permanently attached via a flange to the bottom of the lower torso. The basic structure is wood, which is coated with fiberglass and epoxy for pressure retention.

Incorporated into the lower torso is the Integrated Maneuvering System (IMS). The IMS is divided into four parts: (1) the Hand Control Assembly (HCA), (2) the Thrust Control Assembly (TCA), (3) the Propellant Tank Module (PTM), and (4) the Control Panel.

Hand Control Assembly (HCA)

The HCA consists of two manual controllers. One controller provides translation capability in three mutually perpendicular planes while the other provides rotation about the three axes. The rotation controller also has finger switches for fore and aft translation. This is to allow the crewman to translate and rotate with one hand thus freeing the other to carry loads.

Thrust Control Assembly (TCA)

The TCA includes the thrusters, logic circuit and wiring, solenoid valves, and miscellaneous tubing. Once a signal is generated by either Hand Controller, the logic circuit passes it along to the proper solenoid valve and refuses to accept any other signal until the original is cancelled. The solenoid valves open allowing gas to flow from the inlet manifold to the thrusters required to provide the acceleration called for.

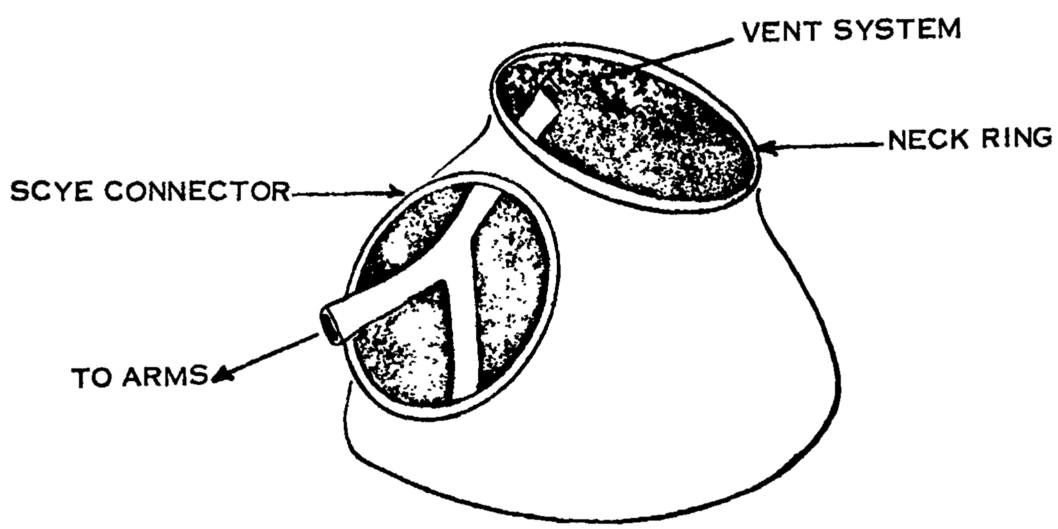


FIGURE 9. UPPER TORSO

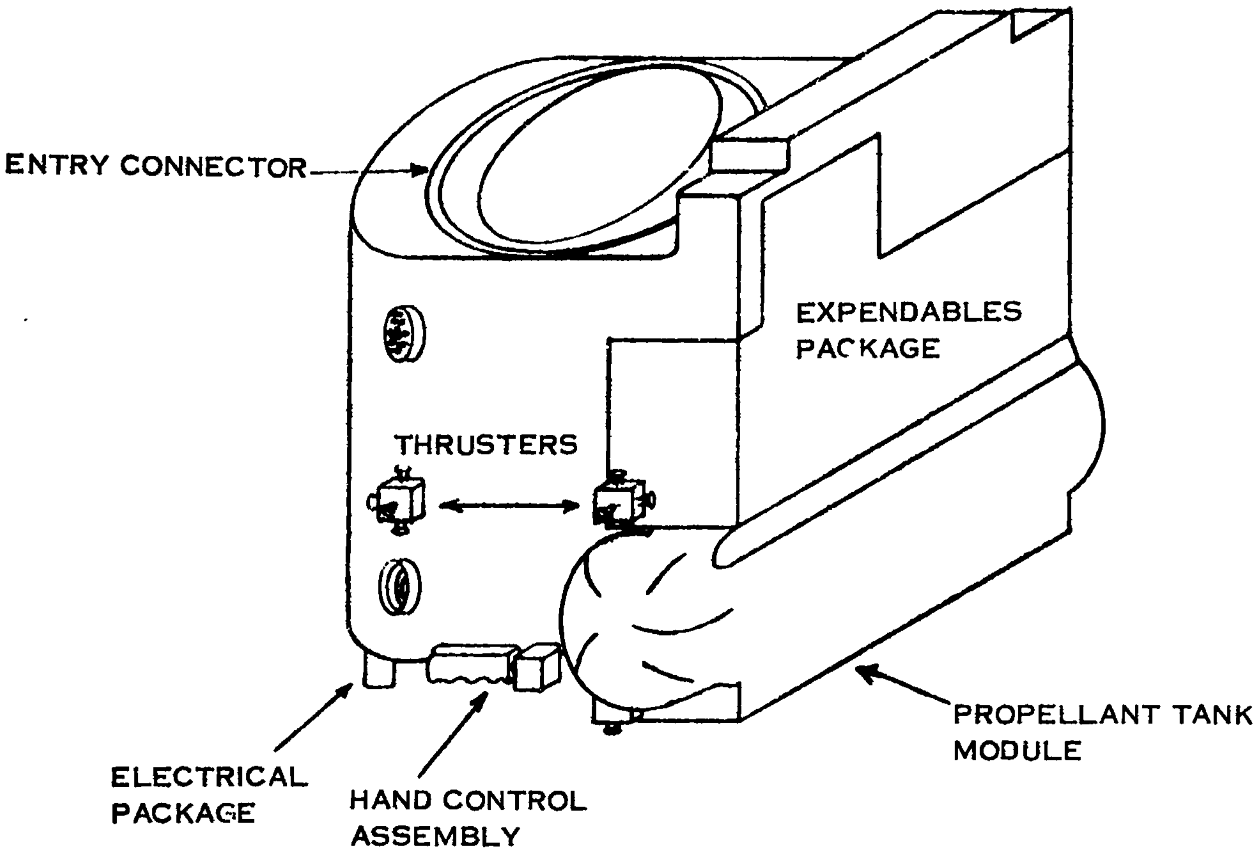


FIGURE 10. IMLSS LOWER TORSO

Propellant Tank Module (PTM)

The PTM is a wooden mock-up, which in real life would supply the oxygen gas required for propulsion plus that needed for emergency return purposes. Approximately 10 pounds of gas at 7500 psig are contained within the cylindrical tank. The mock-up also simulates the envelope of a shutoff valve, which would release the oxygen to a single stage regulator set to 5 psig outlet pressure for emergency use. The human factors mock-up propulsion gas is air and is provided at the rear of the lower torso. 115-volt 60-cycle a-c power to operate the solenoids and the HCA is supplied from another umbilical in the same location.

Control Panel

The control panel is mounted on the front of the suit for visibility and accessibility as shown in Figure 8. It contains those controls and displays necessary to monitor and operate the system. Figure 11 shows the layout of the control panel as the crewman sees it. All controls and displays are nonfunctional except the following:

(a) Suit Pressure Gage

(b) Primary Battery Switch

(c) TCA Light

(d) Liquid Cooling Garment Connectors

These items are functional for proper operation and control of the Human Factors Mock-up.

Soft Suit Arms and Legs

The arm and leg portions of the suit are soft and flexible as street clothing in the depressurized state. When pressurized, they become semi-rigid, yet provide more than 90% of nude range of motion. Actuation forces range typically from 5 to 20 ft-lb. The inner blade layer is an impermeable neoprene impregnated nylon. The outer restraint layer is a porous, high strength, 8 oz/yd^2 nylon whose purpose is to carry the pressure load from the bladder layer. Additionally, an external restraint sys- of Teflon coated cables supports the plug loads, thus allowing the convoluted joint systems to operate properly.

STOWAGE AND RETRIEVAL

This section of the MEP describes the procedures to stow and retrieve the human factors mockup of the IMLSS space suit.

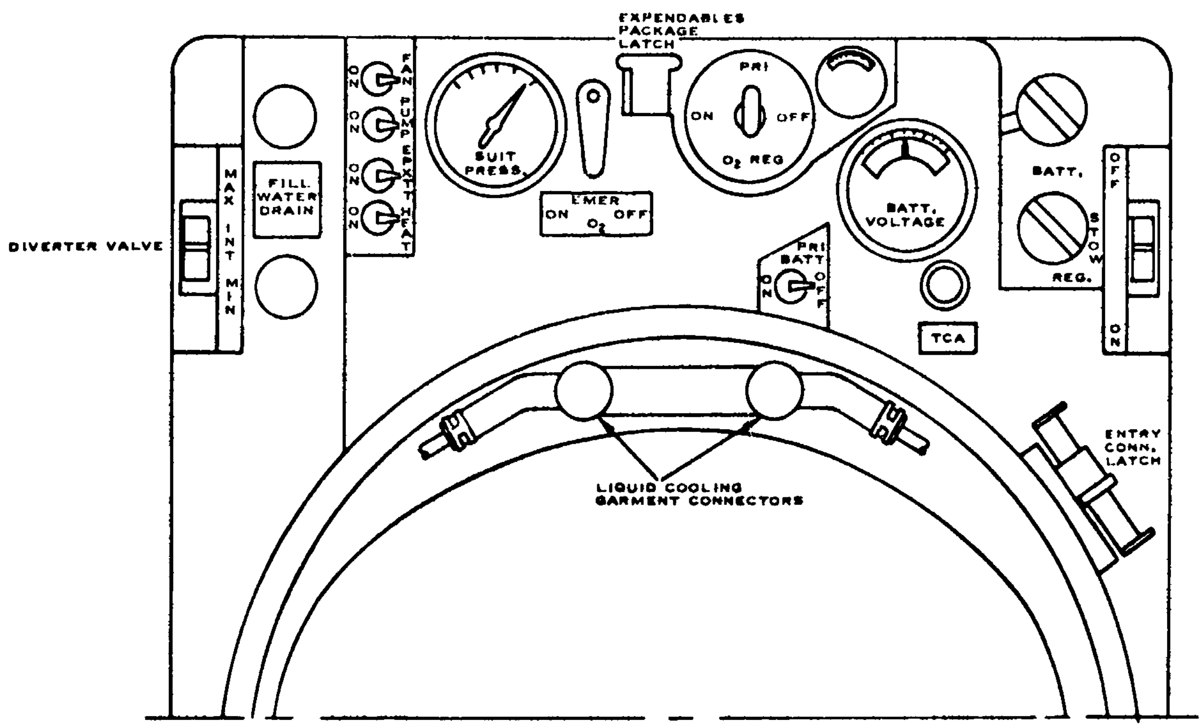


FIGURE 11. CONTROL PANEL

Stowage

- Verify electrical and propellant umbilicals are disconnected from the doffed suit.
- Detach the helmet.
- Attach the upper torso with gloves donned.
- Admit 6 to 12 cfm through the exhaust gas connector until suit interior is dry.
- Verify expendables and PTM packages are attached.
- Reattach helmet and stow in a cabinet between 60°F and 80°F and 40-80% relative humidity.

Retrieval

- Remove from cabinet.
- Detach helmet.
- Detach torso and gloves.

DON/DOFF

The first section of the suit to be donned is the lower torso with soft pants attached. This is donned by laying it front down on the floor with the pants straight out. The crewman enters feet first and face down. After inserting himself, the crewman stands upright. Shoulder straps are then attached to hold the assembly in place while donning the upper torso. This upper section is donned T-shirt style with soft arms attached, but gloves and helmet not attached. The closure connector is mated by pressing downward on the upper torso until the latching ring snaps into place. Locking is accomplished by moving the lock slide to the right as viewed from above by the crewman until the latching ring is secured. This will be indicated visually by the disappearance of the word "open" and the appearance of the word "closed" on the latching device. The system is now ready for checkout prior to donning the gloves and helmet. The gloves are donned by setting the white locking tabs to open and mating the wrist and glove connector halves. The tabs are then rotated to the lock position. The helmet is donned by placing it over the neck ring assembly and pushing down until a click is heard. The latch is then locked by moving it to the crewman's right.

The first step in doffing the suit is to remove the helmet and the gloves. The closure connector latch is then actuated and the upper torso separated and doffed. To doff the lower torso, loosen the shoulder straps, lay face down on the floor and exit.

FIT AND MOBILITY

Fit

The human factors mock-up of the IMLSS has been sized to fit a medium regular crewman as specified in WADC-TR-56-365-A, Height-Weight Sizing System for Flight Clothing (8 Size Height-Weight Program). The design has assumed that the crewman will be wearing a liquid cooled garment (LCG). If such is not the case, a slightly larger crewman can be accommodated. The following dimensions represent the nominals plus the deviations that can be tolerated.

	Nominal Inches	Deviation Inches
Total Body Height	70.5	± 0.5
Crotch to Acromion Height	25.0	± 0.5
Buttock Circumference	36.0	± 1.5
Scye Circumference	18.0	± 1.5
Floor to Crotch Height	33.0	± 1.0
Scye to Finger Tip Length	29.0	± 1.0

Mobility

Mobility in a pressurized suit is highly dependent on how well the crewman fits. Therefore, the crewman used should be sized as close to the nominal dimensions listed in the preceding paragraph as possible. The following table lists the motions that a properly fitted crewman is capable of in the pressurized suit with the corresponding range and torque.

TABLE IV
IMLSS JOINT RANGE AND TORQUE

Motion	Range Degrees	Torque Ft/Lbs
Shoulder Adduction-Abduction	140	30
Shoulder Lateral-Medial	150	30
Shoulder Flexion-Extension	150	30
Elbow Flexion-Extension	140	10
Wrist Adduction-Abduction	40	5
Wrist Flexion-Extension	80	10
Hip Flexion-Extension	30	10
Knee Flexion-Extension	130	12
Ankle Flexion-Extension	60	12

The small range of the hip joint is due to interference with the PTM and its mounting brackets. Studies have shown that 30° of flexion are adequate for walking in a gravity environment.

CHECKOUT-STARTUP AND SHUTDOWN

Checkout-Startup

System checkout is normally done by the crewman after donning all except the helmet. The below listed procedures are then accomplished to assure proper performance.

(1) Admit 6 to 12 cfm of air to the exhaust gas connector to ensure crewman comfort during checkout.

(2) Verify that the master solenoid switch is in the off position and that the a-c indicator light is off.

(3) Verify that the Hand Control Assemblies are properly attached.

(4) Attach a-c umbilical.

(5) Actuate master solenoid switch and verify that the indicator light is on.

(6) Turn off master solenoid switch.

(7) Connect propulsion gas umbilical and verify pressure of 150 ± 5 psig.

(8) Turn on master solenoid switch.

(9) Actuate Hand Control Assemblies in each mode of operation and verify gas flow through appropriate thruster.

(10) Shut off air flow through exhaust gas connector and change connector to inlet.

(11) Connect outlet gas umbilical and adjust flow to subject comfort.

(12) Connect liquid cooling umbilical and adjust flow to subject comfort.

(13) Attach helmet and pressurize suit to 5.0 ± 0.2 psig. System is ready for Operation

Shutdown

The following procedure is to be adhered to at the completion of testing to prepare the system for doffing and stowage.

(1) Turn off the master solenoid switch. Verify a-c indicator light is out.

(2) Depressurize suit to ambient.

(3) Remove helmet and gloves.

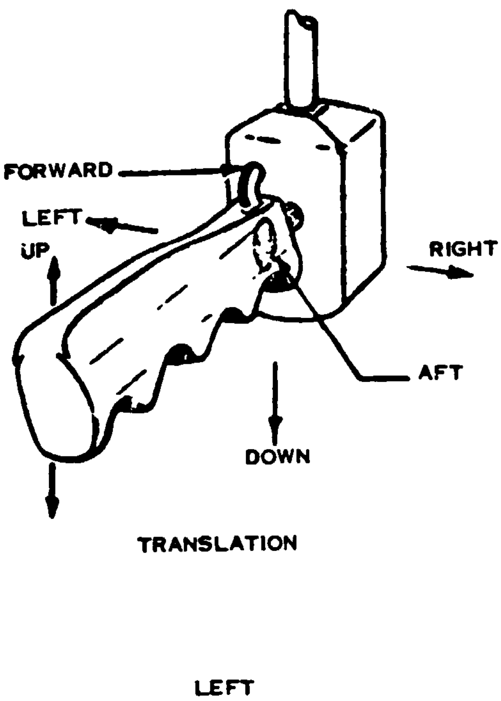
(4) Disconnect propulsion gas umbilical.

(5) Disconnect electrical umbilical.

(6) Disconnect vent gas umbilical. System is ready for doffing.

OPERATION

This section of the MEP describes the various modes of operation of the maneuvering system. Figure 5 is a schematic representation of the thrusters and their placement about the three axes of the man-suit system. The accompanying table tells which thrusters fire to produce a given motion and what acceleration is produced for a 332-lb man-suit system. Figure 12 depicts the Hand Control Assemblies and the movements required to generate the signal to initiate translation or rotation on the roll, pitch, and yaw axes. The following modes of operation will be evaluated:



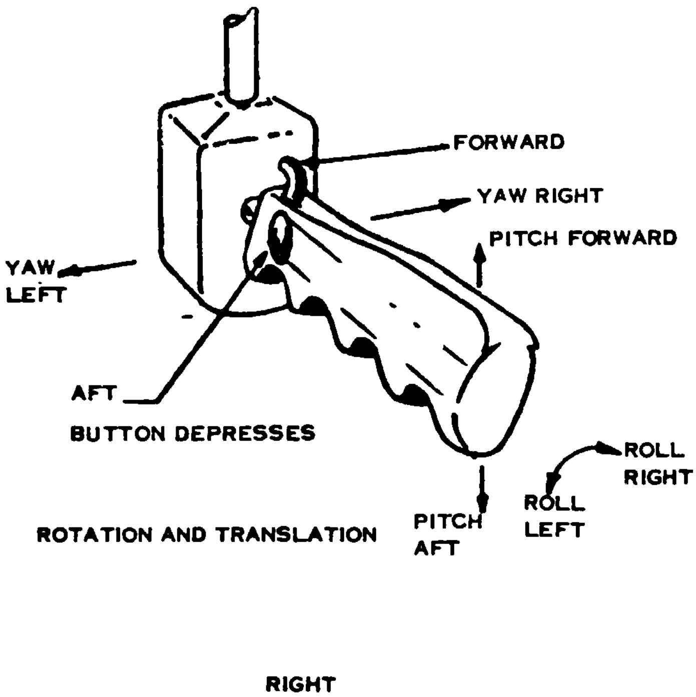


FIGURE 12. HAND CONTROL ASSEMBLY OPERATION

a. Operating Characteristics

b. Translation - Rotation

c. Work Station Positioning

d. Reach Envelope

e. Load Carrying

Operating Characteristics

The purpose of this portion of the mock-up evaluation is to determine and familiarize the crewman with the operating characteristics of the system. This will be accomplished by having the crewman perform the tasks and evaluations delineated below.

Don/Doff

The crewman will don and doff the suit no less than ten times before giving an opinion as to the ease which this operation may be performed. He will then give his evaluation of the following:

Lower Torso Don/Doff

Upper Torso Don/Doff

Entry Connect/Disconnect

Glove Don/Doff

Helmet Don/Doff

This evaluation should include difficult operations, easy operations, and recommendations for hardware repositioning if warranted.

Reach Envelope

This exercise will acquaint the crewman with the reach envelope of the suit system in the pressurized and unpressurized states. The suit will be donned and each motion performed with the suit depressurized until the crewman feels familiar with it. The suit will then be pressurized with air to no greater than 5.0 ± 0.2 psig and the motions repeated. This may take several trials if the subject is unfamiliar with pressure suit work. The following motions will be performed starting in the standing position with the arms down at the sides. Each motion is to be performed with both arms or legs, whichever is pertinent.

(a) Reach the following points:

1) Top of the helmet

2) Opposite shoulder

3) Middle of the back

4) Each instrument on the control panel

5) Expendables Package latches

6) PTM latches

7) Hand Controller Assemblies

(b) Do the following:

1) Fore and aft waist bend to suit limits

2) Spread legs to suit limit

3) Step up on highest possible step

4) Deep knee bend

Propulsion System

This section of the Operating Characteristics provides the crewman with a working familiarity of the propulsion system. All exercises in this section are to be performed with the suit donned and pressurized. Approximately 12 cfm of air should be flowing through the vent system to assure subject comfort. The high pressure (150 psig) umbilical should be attached and pressurized. Tne electrical connector should be connected and the master control switch on the control panel in the OFF position.

An analysis of the circuitry from the HCA's to the solenoid valves reveals that the delay time from the closing of a given switch in a hand control to full opening of the appropriate solenoid valves is slightly more than 12 milliseconds. This is shown in Table V which sums up the various delay and rise times of the electronic and mechanical components.

TABLE V

ELECTRONIC AND MECHANICAL COMPONENT DELAY AND RISE TIMES

Component	Delay time	Rise Time	Total Delay
Integrated Circuit Gates (4)	0	30 nanoseconds	120 nanoseconds
2N3053 Transistor	30 nanoseconds	70 nanoseconds	100 nanoseconds
2N3244 Transistor	15 nanoseconds	35 nanoseconds	50 nanoseconds
Driver Relay (BR-5)	[illegible] milliseconds	0	4 milliseconds
Solenoid Valve	8 milliseconds	0	8 milliseconds
		TOTAL	12+milliseconds

Translation - Rotation

The crewman will position himself on the test rig (air-bearing platform) in the orientation required to evaluate the desired modes. These are: (1) standing for fore-aft and side-side translation plus yaw rotation, (2) lying on his back for up-down (head-foot) and side-side translation plus roll rotation, and (3) lying on his side for fore-aft and up-down translation plus pitch rotation. The power switch should be turned on and verified by the green light on the control panel. Each movement should be accomplished by short (0.5 to 2 seconds) bursts in a chosen direction and then the appropriate counter thrust applied to produce zero motion. All movements are to be accomplished with both hands on the hand control assemblies and the legs slightly spread and straight. An additional part of this exercise will be an evaluation of the hand controller position and actuation modes. The crewman will comment on the comfort and ease with which the hand controllers are reached and actuated in each of the translations and rotations to be performed. A subjective evaluation of the range of motion required to actuate and deactuate each mode plug the torques required is desired. Additionally, an assessment of the suitability of each hand controller motion with respect to the thrust it produces is to be given by the crewman.

After proficiency in single modes has been attained, the effect of arm and leg position will be evaluated. This will consist of repeating the same maneuvers as before with the arms and legs in the noted positions:

(1) Translation - Opposite arm straight out, straight up, and straight forward.

- Repeat with elbow bent 90°.

- Legs apart - knees straight, legs together - knees bent.

(2) Rotation - Same as translation for all axes.

The attainment and cancelling of multiple thrust modes will be evaluated. This will involve two translations, a translation and a rotation, or two translations and a rotation. The following multiple motions will be evaluated for precise attainment and cancellation to zero velocity.

Body Orientation	Primary Translation	Secondary Translation	Rotation
Standing	Forward	Left/Right	
	Aft	Left/Right	
	Forward	Left/Right	Yaw Left/Right
	Aft	Left/Right	Yaw Left/Right
Lying on Back	Left	Up/Down	
	Right	Up/Down	
	Left	Up/Down	Roll Left/Right
	Right	Up/Down	Roll Left/Right
Lying on Side	Up	Forward/Aft	
	Down	Forward/Aft	
	Up	Forward/Aft	Pitch Forward/Aft
	Down	Forward/Aft	Pitch Forward/Aft

Work Station Position

A simulated work station will be stationed within the general maneuvering area. The crewman will maneuver to the work station from a pre-selected point "zero" using at least one translatory and one rotary motion. He will repeat the maneuver from each of the three basic positions with a time-to-complete log being kept.

Reach Envelope

The crewman will secure himself at the simulated work station and measurements shall be taken as to the reach envelope of each hand. The reach envelope will be measured with the crewman facing the work station, parallel to the station, and perpendicular.

Load Carrying

The crewman will carry three types of loads weighing 5, 10, and 20 lbs. These types are bulk (bowling ball), and beam (I-beam) and sheet (plywood). The loads will be carried in one hand while operating the maneuvering unit in single and multiple modes as shown in the previous table.

SECTION V

PREDELIVERY EVALUATION AND DEMONSTRATION

Prior to delivery, a preliminary evaluation of the IMLSS mock-up was conducted at Hamilton Standard in Windsor Locks, Conn. Subsequently, a manned demonstration was performed at the NASA Manned Spacecraft Center, Houston, Texas. Torque and range measurements of the suit joints were made in Houston and are described in the Appendix. Manual operation of the propulsion system was performed at both sites as well as an air-bearing flight demonstration at Houston, Texas.

Before any manned operations took place, an unmanned proof pressure and operational checkout was performed. First, the mock-up torso, arms, legs, and helmet were subjected to a proof pressure of 7.5 psig for 15 minutes. Then the IMLSS was examined for failures and permanent deformation. Next, a proof pressure of 225 psig was applied to the high pressure portion of the maneuvering system for 15 minutes. Finally, the pressure was reduced to 150 psig, the 115 V AC source connected, and all thrusters operated using the hand controllers. No failures, malfunctions, or permanent deformations occurred during the unmanned testing conducted.

The following is a summary of the Hamilton Standard test subject comments recorded during the evaluation in Windsor Locks and demonstrations at the NASA Manned Spacecraft Center. The subject's dimensions are a nominal medium-regular according to WADC-TR-56-365-A, Height-Weight Sizing System for Flight Clothing (8-size Height-Weight Program).

DON/DOFF

The entire IMLSS can be donned unaided, with some difficulty. Learning is apparently quite beneficial as most of this difficulty disappears after 4-5 donnings. The shoulder straps were too narrow to prevent the lower torso weight from being uncomfortable and were not used in later donnings. The upper torso alignment key was difficult to see during alignment. However, once alignment was achieved, mating and locking of the upper and lower torso sections with an audible "click" followed easily.

FIT AND COMFORT

System weight causes increasing discomfort with wear time. This problem was foreseen but due to the mass/propulsion characteristics simulation requirement, it was unavoidable. A weight carrying fixture should be added to air-bearing facilities to preclude intolerable subject discomfort. This problem would not exist in normal earth orbit use.

The GFE wrist rings have a very small ID and chafe the subject's wrists and hands. Wearing long johns and thin cotton gloves alleviates the problem somewhat; however, a larger set of gloves and wrist disconnects should have been supplied.

CONTROLS AND DISPLAYS

All controls and displays on the control panel were 100% visible and accessible. The subject was able to read and actuate all switches, levers, and connectors whether functional or not. The Hand Control Assemblies were easily reached and operated in all modes by the suited pressurized test subject. The Hand Control Assembly retention mechanism did not have the anticipated strength and occasionally was inadvertently separated during propulsion checkout. A stabilizer was added to improve the connector mechanism before shipment to Houston.

MOBILITY

The operation of the suit joints was slightly more difficult at 5.0 psig than at 3.7 psig. However, the degree of difficulty was well within tolerable limits. The GFE Gemini gloves had very poor mobility which resulted in some difficulty in operating the Hand Control Assemblies. A few pressure points were noted in the shin and forearm areas which were quickly removed by root cord and restraint system adjustment.

RECHARGE

Numerous removal and replacement operations were carried out with the primary expendables package and the propellant tank module. These were conducted at a suit pressure of 5.0 psig. While success in this endeavor was obtained on the first and every try, a learning curve was apparent. The degree of difficulty after 15 to 20 operations was about half that originally encountered. The propellant tank module was consistently the more difficult package to handle due to its lack of a grip.

PROPULSION

This part of the predelivery was performed only at Houston where an air-bearing pad was available. Propulsion system operations in the pressurized and unpressurized IMLSS were carried out by the Hamilton Standard subject with NASA engineering and human factors personnel present. Fore and aft translation, lateral translation, and yaw rotation was performed with the subject standing. The remaining modes with the subject lying down on his back and on his side were not done, because the test cradle was not operational. Additionally, station keeping and load carrying capabilities were demonstrated.

In summary, all IMLSS broad performance requirements were verified by a Hamilton Standard test subject during pre and post-delivery operations. The few problems that occurred during these demonstrations were corrected by Hamilton Standard engineering personnel on the spot and are typical of those expected on mock-ups. Following the performance of these tests, the IMLSS Human Factors Mock-up was received and signed for by a NASA representative.

RECOMMENDATIONS

The following recommendations are made in light of the conclusions reached in the preceding section and in the interest of maximum utilization of the knowledge gained during the course of this program.

- Specific design approaches to IMLSS concept implementation should be generated using mid and late 1970's mission requirements.

- Latest state-of-the-art mobility devices for the IMLSS arms and legs should be used.

- Fabrication and test of an IMLSS prototype should be incorporated within existing Orbiting Work Shop or Space Station mission evaluation requirements.

- Appendix evaluation results, which compare the IMLSS to the latest state-of-the-art suits and flight type design, should be used to generate a flight prototype design.

CONCLUSIONS

This section lists the program conclusions reached. These were formulated as a result of the design, fabrication, and evaluation of the IMLSS Human Factors Mock-up.

- Donning and doffing of the IMLSS will require less time than that required for present day systems.
- Total stowage volume for the IMLSS is less than that required for equivalent but separate functional units.
- Mission overhead consisting of recharge facilities, interfaces, and expendables stowage would be reduced by use of the IMLSS modular recharge approach.
- The IMLSS controls and displays grouping and location are superior to rear mounted systems.
- Maximum detachability of integrated IMLSS modules will increase mission flexibility.
- The IMLSS approach is valid and represents the maximum degree of suit, life support, and maneuvering system integration.
- Incorporation of latest state-of-the-art suit and life support system refinements will result in a system which is far superior to the current design.

APPENDIX

INTEGRATED MANEUVERING
LIFE SUPPORT SYSTEM

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INTRODUCTION

This report describes the results and conclusions arrived at through performance testing of the IMLSS Human Factors Mock-up by NASA personnel. The basis for this evaluation was the Mock-up Evaluation Plan (MEP) which has been previously described. Also, to obtain a comparison with present day astronaut protective systems, NASA conducted additional investigations outside the scope of the MEP. Included in this report are their comments and recommendations on specific design details which should be incorporated into a future IMLSS flight prototype.

IMLSS HUMAN FACTORS MOCKUP EVALUATION REPORT

1.0 INTRODUCTION

The IMLSS (Integrated Maneuvering and Life Support System Suit) consists of an EVA space suit design with a cold gas propulsion system and a self-contained portable life support system incorporated into the torso section. This integration design represents the latest concept in EVA hardware. History and design information fo~ the IMLSS concept can be found in Hamilton Standard reports SVHSER 5155 and TP-69-10-T. Martin Marietta Corporation report MCR-69-184 describes the mobility performance during simulation exercises using the IMLSS concept.

Hamilton Standard, under contract with NASA and U.S. Air Force, fabricated a human factors mockup repr~sentative of the IMLSS concept. This mockup was delivered to NASA-MSC (Manned acecraft Center) for evaluation testing at the Crew Systems Division facilities.

The evaluation testing on the mockup was performed according to the contract statement of work and according to the MEP (Mockup Evaluation Plan) provided by Hamilton Standard. From the MEP, a thorough checkout list was prepared for recording the subjects comments during the evaluation. Three NASA test subjects and one astronaut donned and doffed the IMLSS mockup for the evaluation. Their comments are compiled in this report as recorded in the areas listed in the checkout list.

1.1 OBJECTIVE

Since this IMLSS concept has not been assigned to a specific mission, the concept was not compared with the currently available EVA orbital equipment to see which equipment would better meet the specific mission requirements. This evaluation was concerned with refining the design of the IMLSS concept, as according to the MEP.

1.2 SCOPE

The areas evaluated according to the MEP include the fit, reach, component/controls placement, and procedures. The procedures include unstowing, donning, checkout, operation, recharging, doffing, and stowing the IMLSS mockup and support hardware. This report lists the comments of the subjects as recorded in these areas.

1.3 CONCLUSIONS

The protocol of the MEP was not meant to provide an indication of the desirability of suit/life support/maneuvering systems integration as a concept. The various features subjected to evaluation do not lend themselves directly to such an output, so some interpretation of results is required.

In this section, conclusions concerning each element of the evaluation are presented, along with a final summation of the validity of the IMLSS concept. Details pertaining to the evaluation process and results are contained in Section 4 and recommendations in Section 6.

1.3.1 Reach

The accessibility of controls was found to be a function of the suit mobility, as was the removal and placement of modules.

Conclusions: With incorporation of state-of-the-art improvements in suit arm joints, the IMLSS approach to controls and modular placement is suitable, and probably superior to recharge of a backpack.

1.3.2 Donning and Doffing

Although several minor problems were experienced, both in design and operation, the IMLSS could be donned and doffed without undue difficulty. Donning station provisions in the spacecraft would be a must, however.

Conclusion: Donning/doffing of the complete suit/life support/maneuvering system definitely would be a valuable time saver.

1.3.3 Stowage and Retrieval

Minor design problems (sharp edges, high stress at cable fittings) exist, but are peculiar to the hardware, not the concept.

Conclusion: Total stowage is much less than for separate but equivalent functional elements; however, stowage of expendable modules might inflict unacceptable vehicle penalties in terms of weight and volume.

1.3.4 Recharging

Problems with glove fit (poor tactility) and module alignment occurred; however, all recharges were made successfully.

Conclusion: Mission "overhead" could be considerably reduced by use of modular recharge.

1.3.5 Controls and Displays (including hand controllers)

The lack of arm mobility influenced this evaluation, and it is felt that additional controls and displays should be added; however, the overall evaluation was successful.

Conclusion: Necessary controls and displays can be suitably grouped and reached as in the IMLSS and this is superior to having rear mounted controls.

1.3.6 Other Factors

The requirements for a particular mission could have an impact on the amount of integration which would be desirable. For example, plans to use the IMLSS, both on the lunar surface and in orbit during a mission, would favor an approach in which the entire maneuvering system was detachable.

Use of the suit portion of the IMLSS during an emergency situation might dictate a completely removable torso section and reliance on a parent vehicle for life support.

Conclusion: The degree of nondetachable integration should be minimized, so as to maximize flexibility.

1.3.7 General

Conclusion: The IMLSS approach represents the maximum degree of suit, life support, and maneuvering system integration. The concept is valid and specific design approaches should be generated from mission requirements.

2.0 MOCKUP CHANGES

The mockup was delivered to MSC in September 1969 for the evaluation. Preliminary testing showed the need for several changes to the mockup. Listed are the mockup changes requested by NASA and accomplished by Hamilton Standard at Windsor Locks, Connecticut.

2.1 The Gemini gloves and wrist disconnects on the mockup were replaced by MOL gloves and wrist disconnects furnished to Hamilton Standard.

2.2 The maneuvering system hand controller latches were replaced with thumb nuts and studs to prevent the hand controllers from becoming inadvertently detached. Several thrusters would fail open if a hand controller was detached. This condition was a possible safety hazard for the air bearing pad mobility simulations.

2.3 The mounting rails for the modules were changed to permit easier mounting and to prevent binding.

2.4 Foam pads were added under the shoulder straps to help distribute the weight of the suit on the subject's shoulders.

2.5 New torso alignment marks were added near the torso latch for better visibility.

2.6 The sharp edges on the torso fiberglass shell were made smooth.

2.7 The thruster control unit light was replaced with a flatter light to prevent possible breakage by the arm restraint cable while the suit was unpressurized.

2.8 The Yaw controls were switched, by NASA personnel after preliminary air bearing mobility testing, to give response in the expected direction.

2.9 The inside leg restraint cable terminals were straightened and the mounts replaced.

3.0 MOCKUP REPAIRS

During the course of the preliminary testing and evaluation, problems were encountered that required repair by either Hamilton Standard or NASA. These are listed below.

3.1 The electrical connector for the hand controller broke and was replaced by Hamilton Standard during the suit changes.

3.2 The left leg outer restraint cable broke at the hip swage fitting and was replaced with a new cable and fitting. The fitting and swivel mount were redesigned to relieve the bending stresses on the fitting.

3.3 The Y manifold block for the two leg air exhaust ducts was broken loose twice from the torso section and was epoxied back in place.

3.4 A relay failed open in the thruster logic circuit and prevented one thruster solenoid from firing. This was replaced.

3.5 The left elbow restraint cable broke at the swage fitting and was replaced.

Movement of the restraint cables while the suit was unpressurized would, at times, kink the cables at the fittings, providing a high stress point which weakened this cable.

4.0 EVALUATION COMMENTS

The following sections of this report summarize the test subject's comments in the same sequence as they were recorded in the checkout list. The areas covered are as specified in the MEP.

4.1 FIT

The IMLSS mockup has been sized to fit a medium regular crewman. Each subject was measured to determine their deviations from this size. The three NASA test subjects were long one inch in the crotch to acromion height and short one inch in the floor to crotch height. The astronaut was the right size.

4.1.1 Fit in Lower Torso

When the suit was pressurized to 3.7 psig, pressure points were noted on the front of the shins on all the subjects. The points were attributed to the weight of the suit causing the collapse of the convoluted section just below the knees.

The diameter of the leg sections at the upper thigh is small, causing a tight fit on two of the subjects.

The comment was made that the suit seemed to "ride up" in the crotch area.

4.1.2 Fit in Upper Torso

The crotch to acromion height is critical in the hard upper torso section. The fiberglass would press hard into the shoulders if the subject was too long in this dimension.

Pressure points were noted on the arms when the suit was pressurized. These were 4" from the elbow on the upper arm and 3" from the elbow on the lower arm. This pressure was enough to cut off blood circulation and hamper the evaluation. Proper suit fit helped to lessen the pressure.

The shoulder joints were very difficult to move pressurized due to extreme friction in the cable restraint system. The liners for the cable guides were wearing and teflon flakes were being abraded from the guides. A pulley system or sturdier liners for the guides are needed to reduce the friction.

The safety locks on the torso latch must be pulled out in order to close the latch. There is no positive clicking into place. Visual cues are used to ensure positive locking.

4.1.3 Fit in Gloves

The smaller Gemini gloves seem to fit the hands of the subjects better than the MOL gloves. The MOL gloves were sized for large size Air Force astronauts.

The arm length increased when the MOL gloves and disconnects were installed. The increased length, although adjusted as short as possible, was such that the subject's fingers were almost out of the glove fingers. This interfered with the grip and operation of the hand controllers and controls.

4.2 REACH

The reach evaluation was done pressurized and unpressurized with an without the expendable module (EM) and propellent tank module (PTM) to determine reach envelope, comfort, and work required. Listed below are the reach exercises and their results.

4.2.1 Top of Helmet

The top of the helmet can be reached with both hands without difficulty, both pressurized and unpressurized.

4.2.2 Opposite Shoulder

Unpressurized - The edge of the fiberglass on the shoulders can be reached.

Pressurized - The fabric at the center of the upper arms can be reached.

4.2.3 Middle of the Back

Unpressurized - The rear of the thruster block can be reached.

Pressurized - Just below the thruster block can be reached.

4.2.4 Each Instrument on the Control Panel

Pressurized - It is hard to bring right arm around to reach toggle switches due to the friction in the shoulder restraint system.

4.2.5 Hand Controller Assemblies

Pressurized - It is difficult to pull elbows back to reach controllers.

4.2.6 Waist Bend (degrees from vertical)

Unpressurized

	Forward	Backward
Without PTM	45°	30°
With PTM	30°	30°

Pressurized

	Forward	Backward
Without PTM	40°	30°
With PTM	40°	30°

The logic module does not interfere with the legs of the suit.

4.2.7 Leg Spread

The suit legs hit the front thruster frames, but not the hand controllers. With the help of the weight of the suit, the feet can spread apart up to 47 to 51 inches.

4.2.8 Highest Possible Step

	With PTM	Without PTM
Unpressurized	12 to 16"	16 to 19"
Pressurized	4 to 8"	8 to 11"

4.2.9 Deep Knee Bend

The legs bind on the front thruster frames without the PTM. With PTM in place, subject cannot do a deep knee bend.

4.3 DONNING AND DOFFING

The mockup was donned and doffed according to the MEP by each of the subjects and their comments are noted here.

4.3.1 Lower Torso

A donning and doffing station would be needed to hold the lower torso hard section and boots in place to permit the subject to shove his legs in and out of the suit legs. The subject cannot bend over easily to pull or push on the legs during doffing, especially if tired.

4.3.2 Upper Torso

In donning the upper torso, the control panel was struck repeatedly by the upper torso edge and the outer controls were hit and moved by the suit arms. The shell would also catch in front of the sublimator. The arm restraint cables rub on the top sides of the control panel. The lower arm sections were frequently turned wrong and the large amount of fabric in the arms prevented easy remedy by the subject. The alignment tab near the torso latch could be seen and aligned with no problem. There is no audible indication or click when the torso ring is mated all around. The torso ring is difficult to pull together to mate by just the suited subject, especially if the suit is not the right fit. The torso latch is very difficult to reach and operate by the suited subject, even without gloves. This would be an undesirable condition if a tired subject has to unlatch himself.

4.3.3 Gloves

The gloves donning and doffing presented no problems.

4.3.4 Helmet

The helmet latch cannot be seen in its entirety. The latch is difficult to grasp with bare hands.

4.4 STOWAGE AND RETRIEVAL

The legs can be folded up against the torso section to give a smaller stowage volume. However, the present leg restraint cables can be broken at the fittings because of the bending stress points. No other problems were seen in stowage and retrieval by an unsuited subject other than the weight and the mockup's sharp edges.

4.5 RECHARGING

The expendables module (EM) and the propellant tank module (PTM) were attached and detached several times, both while the mockup was pressurized and unpressurized. Pressurized operation was more difficult due to the loss of fine feeling from poor glove fit.

The push button latches are not easily found and have no safeties. Hence, the modules could become inadvertently detached. The flight type module locking mechanisms are needed for the evaluation of force required, safety, operation, etc.

There is no way presently to tell if both modules are engaged securely. A visible mechanical sign should be used to show positive module engagement.

The oxygen, suit loop, etc. connectors need to be placed on the modules and torso section for evaluation of module locking mechanisms, forces required, alignment, etc. The astronaut subject expressed concern for an oxygen umbilical connector on the mockup for a backup in case of an emergency while refurbishing the suit.

4.5.1 EM

The alignment mark on the EM helped in guiding the module into the rails. However, present rail guides for mounting the modules are too critical on initial engagement.

Tolerances are such that modules will bind while attaching or detaching. Ramp or "funneling" guides are needed for the initial engagement.

The slots in the side of the EM are hard to feel and use. Fold-out handles, thumb holes, or positive grips are needed for secure grasping of the modules for attaching and detaching.

The electrical connector for the EM is very difficult to work in its present location by the suited subject pressurized or unpressurized. The connector could be moved to the back of the EM to mate when the EM was attached.

4.5.2 PTM

The emergency O_2 valve located on the PTM cannot be seen and is hard to find at first. This valve has no provision for protection from accidental activation. There is an emergency O_2 valve located on the panel that could be used instead.

4.6 CONTROLS AND DISPLAYS

The control panel was evaluated as to visibility, ease of reach, force required, accidental activation protection, grasping, completeness, method of operation, proper labeling, spacing, etc. The following comments were noted.

4.6.1 The sublimator feedwater shutoff valve and suit cooling diverter valve are very vulnerable to accidental activation. Reaching these outer panel valves is difficult due to the suit arm mobility. The diverter valve and feedwater valve should be actuated by a knurled knob or a well protected lever. More detented positions are needed on the diverter valve.

4.6.2 Present suit arm mobility prevents a pressurized subject from reaching and operating the water fill and drain connectors in their present location. The connectors could be moved off the panel and placed on a 45° foldout panel out of either side of the control panel for accessibility.

4.6.3 The switches have a positive feel and click. They are activated by flipping with the glove fingernails, not by gripping. The Apollo switch spade handles are preferred by the astronaut and subjects. The switches could be angles 45° to the front to reach and operate easier. Wicket switch guards could be used in place of the two safety switch covers.

4.6.4 The controls for primary O_2 and emergency O_2 are not standardized with one on-off direction and activation direction. There is no protection for the primary O_2 lever.

4.6.5 Labeling was not done per MIL-STD-1472, Human Engineering Design Criteria . . . Many of the labels are not completely visible or readable to the suited subject. These are unsatisfactory.

4.6.6 The battery voltage gauge will not show the charged condition or existing life in the battery. A low battery voltage display could be used to indicate the need for switching to the emergency battery.

4.6.7 Based on the PLSS RCU displays, a lighted display cannot be seen in the sunlight. Recessed mechanical flip flops with flags are preferred. The walls of the recesses are coated with luminous material for lighting while the panel is not in the sunlight.

4.6.8 The distance to the control panel from the subject is satisfactory, although the panel could be slanted up toward the subject to reduce the parallax.

4.6.9 There are no locations or provisions made on this mockup for mockup communications controls such as channel selector, push-to-talk button, and volume controls.

4.6.10 The following selected controls, displays, and connectors should be placed either on the panel or on the side of the panel.

Gauges	Connectors	Switches and Controls
Primary O_2	Feedwater Fill	Fan
Emergency O_2	Feedwater Drain	Pump
Suit Pressure	O_2 Umbilical	Communications Selector
Feedwater Quantity	Communications	Volume Control
		Push-to-talk/VOX Switch
		Thrusters On/Off
		Main Power On/Off
		Emergency Power On/Off

Valves	Warning Lights and Displays	
Primary O_2	O_2 High Flow	Main Power On
Emergency O_2	Suit Low Pressure	
Feedwater Shutoff	Low Feedwater	
LCG Diverter	Low Battery Voltage	
	Emergency Power On	
	Thrusters On	

4.7 THRUSTER HAND CONTROLLERS

Due to the large size gloves used, gripping of the hand controllers (HC) properly was difficult. With properly fitted gloves, the subject will have better feel and control of the HC.

4.7.1 There is excessive angular movement in the HC to fire a thruster and not enough return force. The M-509 experiment specifies 2° movement from center. This gives the subject a faster response time and more of a feeling of how long the thruster has fired.

4.7.2 The HC mounting latches were changed to thumb nuts and studs to prevent accidental unlatching when being used and to give a more stable mount. A finer alignment is needed on the studs just as the HC electrical connector mates.

4.7.3 The HC safeties were taped closed due to the lack of fine feeling in the gloves. The thruster on-off switch on the panel could be used as the safety since operation of the safeties was difficult using the palm of the glove. The subject in using the safety would not grip the HC, but use his thumb.

5.0 MOBILITY SIMULATION

The IMLSS suit was placed several times on the air bearing facility at NASA-MSC and numerous standing maneuvers were attempted. Trouble was experienced with the air bearing pad grounding out and adding unwanted torques to the maneuvers. This grounding out was due to the condition of the pads and to the weight of the subject, the IMLSS, pad platform and bottles. The unwanted torques prevented the taking of useful data from the maneuvers; however, the suit thrusters were easily managed and no subject had any loss of control. The IMLSS maneuvering evaluation was to be rescheduled on another air bearing facility, but conflicts have prevented further maneuvering evaluation.

6.0 RECOMMENDATIONS

Based on the evaluation of the mockup, the following are recommendations for refining the hardware used in the IMLSS concept.

6.1 The soft arm and leg suit sections should be made more comfortable and more mobile. The current joint restraint systems should be refined or replaced with such as constant volume joints.

6.2 The inside diameter of the hard lower torso section could be made smaller. There is a large amount of clearance for the subject.

6.3 The upper torso could be a soft section. This would result in a smaller stowage volume and possibly more subject comfort unpressurized.

6.4 The torso mating ring could be angled up higher in the back and could possibly be made smaller if the torso inside diameter is decreased.

6.5 The latest Apollo helmet, latches, and wrist disconnects have been proven out and are recommended for the IMLSS concept. The Airlock water connector is recommended inside the suit to mate with the LCG, to provide a single connection.

6.6 The bubble helmet or an all clear IMLSS helmet will provide better visibility.

6.7 The front thruster frame could be made smaller to prevent interference with legs of the suit.

6.8 New suit leg liners need to be developed such that the subjects' legs will slip easily in and out without binding.

6.9 Foldout handles are needed on the sides of the EM and PTM to help grasp, attach, and detach the modules.

6.10 A visual mechanical sign should be used to show positive module engagement.

6.11 Module attachment guides need to be of a "funneling" or ramp type.

6.12 The emergency O_2 valve should be located well in sight and reach, such as on the panel. There should be provisions against accidental activation.

6.13 Reorganization, relabeling, addition of displays, addition of communications, and warning flags were needed on the control panel.

6.14 The removal of the battery voltage gauge is recommended.

6.15 The logic module does not interfere with the suit and could be enlarged and angled in if needed.

6.16 The water fill and drain connectors should be moved into a more accessible location and workable position.

6.17 The hand controller movement should be refined. The safeties should be removed.

6.18 The thruster nozzles should be made replaceable to allow easy repair and changing of thrust rates.

6.19 There should be provisions for a backup maneuvering system, such as the buddy system or a connector for a hand held maneuvering unit.